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Meteorological Aspects of Air Pollution Control

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Environment Conservation in Ontario

Department of Energy and Resources Management

Hon. George A. Kerr, Q.C., Minister J.C. Thatcher, Deputy Minister

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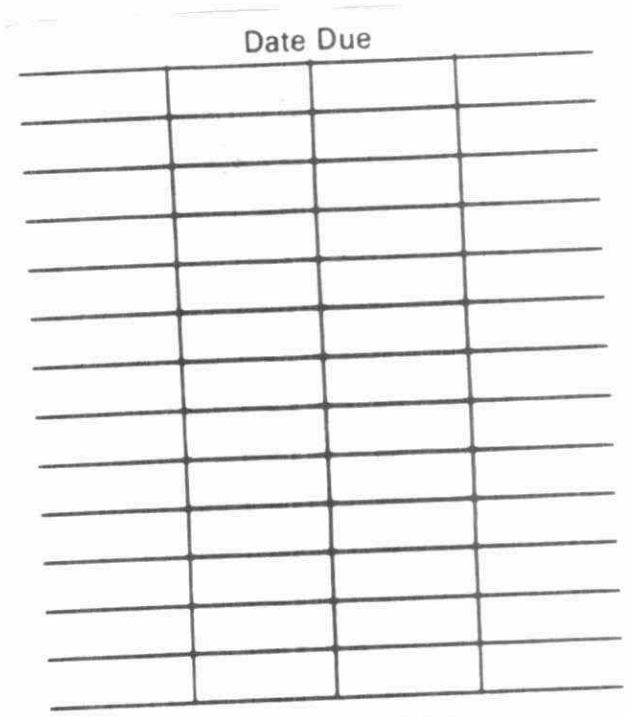

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METEOROLOGICAL ASPECTS OF AIR POLLUTION CONTROL

by

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Introduction

Meteorological factors greatly effect the amount of pollution present in the atmosphere. Temperature and solar radiation, by their influence on the amount of space heating required, affect the quantities of pollutant emitted. Sunshine is required for the photochemical production of oxidants that form smog. Wind velocity, turbulence and stability affect the transport, dilution and dispersion of pollutants. Rainfall has a scavenging effect by washing out particles in the atmosphere. Finally, humidity is a frequent and important factor in determining the effect of pollutant concentrations on property, vegetation and health.

In view of these effects, meteorologists are involved in the following aspects of air pollution control:

1. Forecasting air pollution potential for air pollution control agencies that they may alert industry to carry out temporary abatement action.

2. Selecting sites and designing emission systems for large industrial sources.

3. Establishing air monitoring surveys.

4. Carrying out research in air pollution control methods.

Classes of Pollution Sources

Urban sources of pollution are divided into two classes:

1. Low level emitters - vehicles, combustion sources for space heating of houses and small commercial buildings, privately owned incinerators.

2. High level emitters - stacks serving municipal incinerators, industries and central heating systems for industrial, commercial and institutional multi-building complexes. These stacks are at least 50 meters high.

Meteorological parameters affect ground or "living" level concentrations of pollutants from these two classes of emitters in different ways. In order to provide satisfactory forecasts of air pollution potential for a given area, its micrometeorology and topography must be known in addition to the locations and characteristics of its principal sources of pollution.

Meteorological Factors Affecting Pollutant Concentrations

Meteorological parameters having the most important influence on the diffusion of pollutants in the atmosphere are wind direction and speed, turbulence, temperature and stability.

Wind

Equatorial areas of the world receive more radiation than polar areas. As a result, there is a constant heat transfer from equatorial areas to polar areas to maintain a heat balance. This thermal driving force is the main cause of atmospheric motion or wind over the earth.

In addition, the unequal heating of land masses versus oceans, the effects of mountain slopes facing the sun, etc., also produce air at different temperatures that in turn result in winds because of pressure differentials.

Wind is air in motion in three dimensions. Only the horizontal component, however, is usually considered in terms of direction and speed.

Wind Direction

Wind direction changes with height, normally veering a few degrees (clockwise) depending on the roughness of the terrain. It is always defined as the direction from which the wind is blowing. The "prevailing" wind is defined as the direction from which the wind is most frequent in a given locality. Wind direction indicates direction of travel of pollutants.

Wind direction and its persistence is a very important factor in predicting the air pollution potential of an area in which the principal pollutant sources are high stack emitters located close together. Wind direction is less important where low level emitters cause most of the pollution.

Expected persistence of wind direction, related to topographic features and location of receptors, must also be considered both when forecasting air pollution potential and selecting sites for plants.

Where the principal pollution source is located on a lakeshore, for example, high air pollution potential conditions can be expected only when persistent off-shore winds are forecast. For a city such as Sarnia which has most of its large industry located to the south, pollutant concentrations are high only when persistent southerly winds occur.

Topographical features such as valleys cause winds to persist in certain directions at much greater frequencies than others. Obviously, such localities should be avoided as sites for large industries.

Wind Speed

Wind speed determines the travel time of pollutants from a source to a receptor. Wind speed also has a dilution effect. Pollutant concentrations downwind from ground level sources are inversely proportional to wind speed. Air potential forecasts for most large urban areas where low level emitters are the principal sources of pollution include light wind speed as one of the criteria.

This dilution effect is not true for hot emissions from high stack sources. In these instances, an increase in wind speed lowers the plume rise, thus tending (up to a point) to increase ground level concentrations. There is a "critical wind speed" for each stack design at which concentrations downstream reach a maximum.

Turbulence

High frequency fluctuations in the wind are known as turbulence and they occur in both vertical and horizontal components. These random motions are responsible for the movement and diffusion of pollutants about the mean wind path.

Mechanical turbulence is caused by roughness of terrain -- trees, shrubs, buildings, etc.

Thermal turbulence is due to the earth's surface being heated by the sun. Thermal eddies develop as the air, heating up at lower levels first, becomes less dense and rises. Turbulence or vertical motions are at a maximum during the day and at a minimum during the night.

Temperature and Stability

The temperature of the lower region of the atmosphere (surface to 2 km.) can either decrease or increase (inversion) with height depending on the character of the underlying surface and the radiation at the surface. The amount of turbulence occurring is related to this temperature structure.

Inversion

An inversion occurs when the temperature within a layer of air increases with height above the earth. An inversion inhibits the rise and dispersion of pollutants emitted into the atmosphere. Thus, when pollutants are emitted near the ground during an inversion, they remain and cause high concentrations to develop.

Under reverse conditions, when temperature decreases with height, the warmer air near to the ground and the pollutants emitted into it rise and disperse high in the atmosphere. Concentrations of pollutants in the lower layers of the atmosphere are correspondingly lower.

Three different inversion conditions are possible -- radiation, advection and subsidence.

Radiation inversions are the most common. Ground-based, they develop during clear nights when the air cools off faster near the ground than aloft. They remain until morning by which time their average top height is about 100 meters.

During the morning, as radiation from the sun warms up the ground, the air nearest ground warms up first and the inversion gradually breaks down from the lowest levels upward. If a cloud cover moves in prior to sunrise, however, it will continue during the day and high pollution levels will develop.

Advection inversions occur over land areas neighbouring oceans or large lakes such as Lake Ontario. During the spring and early summer the air over the lake's surface is cooled by the comparatively cool water. The air over the ground (especially in developed cities such as Toronto and Hamilton) warms during the day and rises. The warm air is replaced by the cool air from off the lake thus setting up an inversion in the lower layers of the atmosphere.

Advection inversions average about 100 meters in depth. It is very important that industrial sources on lakeshore sites have stacks at least 150 meters in height.

Subsidence inversions occur aloft and are caused by the sinking motion of air generally associated with large high pressure areas.

The descending motion results from the lateral spreading of air that occurs outwards from high pressure areas. It causes air to be compressed thereby increasing its temperature and creating an inversion in a layer of air aloft.

Subsidence inversions become serious due to both the calm or light wind conditions accompanying high pressure areas and the tendency of high pressure areas to remain virtually stationary for long periods of time. An inversion aloft acts as a cap on pollution emissions, preventing them from dispersing into the high atmosphere.

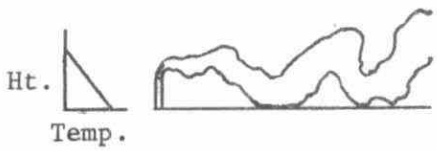
Large subsidence inversions involving thousands of square miles occur over the industrial regions of eastern North America when high pressure areas stagnate there, usually as the western extension of the Azores anticyclone. At these times, high pollutant concentrations occur over urban and valley areas containing large industrial sources of pollution.

Stability

Air stability is determined by the rate at which temperature decreases with height. A neutral condition exists, when temperature decreases at the rate of 5.4 degrees F per 1,000 feet or 1 degree C per 100 metres. When temperature decreases at a greater rate, the air is considered unstable. Light winds and heating from the sun are necessary for this condition to occur. When winds are greater than 6 metres per second, the air will stratify and any instability will tend to break down.

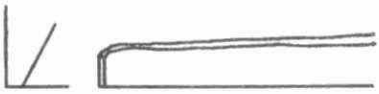
The behaviours of smoke plumes under various stability conditions has been categorized as follows:

1. Looping occurs when the atmosphere is highly unstable (sunny skies and light winds). There is good diffusion. High concentrations may occur for very short time intervals when the plume strikes the ground. Cloudiness and strong winds prevent unstable conditions from forming.

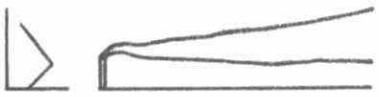


2. Coning occurs when the atmosphere is slightly unstable. Vertical mixing is not as intense as it is when looping occurs. The plume is cone-shaped. Ground level concentrations of pollution from high stacks can be predicted quite accurately. H = effective stack height.

3. Fanning occurs when the atmosphere is very stable (during inversions). There is little vertical motion. The plume meanders horizontally with only slight vertical diffusion. Plume concentrations are high. Ground concentrations vary according to stack height.



4. Lofting occurs when a plume is emitted above an inversion. The plume does not reach the ground but is kept in the unstable air aloft.



5. Trapping occurs when there is an inversion aloft and an unstable layer of air beneath it. The plume is trapped below the inversion layer. High, ground-level pollutant concentrations accompany this condition. It occurs during persisting periods of high pressure or in advance of an approaching warm front.

Controlling Air Pollution

The maximum concentration of pollution downwind from a source is directly proportional to the emission rate of the pollutant and inversely proportional to the square of the effective stack height. The effective stack height is the height of the centre line of the plume above ground. (See figure 2, Page 8.)

Pollution can thus be controlled by reducing the emission rate or increasing the effective stack height. The former is by far the preferred and most effective method of control. Most particulate matter can be removed through the use of efficient precipitators. Sulphur dioxide emissions can be reduced by burning lower sulphur content fuels.

Effective stack height can be increased by simply increasing the actual height of a chimney. It may also be increased by increasing both exit gas velocity and temperature or by combining the effluent from several sources into one larger diameter stack. These design features cause the plume to rise higher above the stack.

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